

X71-74415

(ACCESSION NUMBER)	(THRU)
38	none
(PAGES)	(CODE)
(NASA CR OR TMX OR AD NUMBER)	
(CATEGORY)	
Restriction/Classification Cancelled ONLY	

FF No. 602(A)

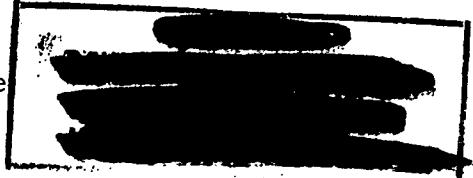
48
Copy
RM SL58B10

NACA

RESEARCH MEMORANDUM

for the

U. S. Air Force



HEAT-TRANSFER AND PRESSURE MEASUREMENTS FROM A FLIGHT

TEST OF THE SECOND 1/18-SCALE MODEL OF THE TITAN

INTERCONTINENTAL BALLISTIC MISSILE UP TO A

MACH NUMBER OF 3.91 AND REYNOLDS NUMBER

CLASSIFICATION CHANGED

UNCLASSIFIED

PER FOOT OF 23.4×10^6 By Authority of John B. Graham Date 3/30/58 COORD. NO. AF-AM-70

By John B. Graham, Jr.

Langley Aeronautical Laboratory
Langley Field, Va.NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

January 29, 1958

THIS PAGE IS UNCLASSIFIED

ERRATA

NACA Research Memorandum SL58B10

By John B. Graham, Jr.
January 1958

Page 16: In column 9 on this page of table I, under the heading N_{St} , all values are in error and should be corrected by moving the decimal point four places to the right, so that the corrected values will be whole numbers consistent with values in other parts of this table. Thus, the first value should be 17.7×10^{-4} and subsequent values should be 12.6, 12.4 . . . 28.4.

Issued 5-21-1958

NACA - Langley Field, Va.

THIS PAGE IS UNCLASSIFIED

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

for the

U. S. Air Force

HEAT-TRANSFER AND PRESSURE MEASUREMENTS FROM A FLIGHT

TEST OF THE SECOND 1/18-SCALE MODEL OF THE TITAN

INTERCONTINENTAL BALLISTIC MISSILE UP TO A

MACH NUMBER OF 3.91 AND REYNOLDS NUMBER

PER FOOT OF 23.4×10^6

COORD. NO. AF-AM-70

By John B. Graham, Jr.

SUMMARY

Heat-transfer and pressure measurements were obtained from flight test of a 1/18-scale model of the Titan intercontinental ballistic missile up to a Mach number of 3.91 and Reynolds number per foot of 23.4×10^6 . With the exception of one station on the nose, turbulent flow was observed over the model throughout flight. Heat-transfer coefficients presented for the accelerating portion of flight were approximately on the order of 20 percent lower than results obtained by available theories; however, during the decelerating portion of the flight, the data were in good agreement with theory. Drag coefficients of the configuration were obtained for a Mach number range of 1.5 to 3.5.

INTRODUCTION

At the request of the U. S. Air Force, the National Advisory Committee for Aeronautics is conducting flight tests of 1/18-scale models of the Titan intercontinental ballistic missile (ICBM). The purpose of these tests is to obtain detailed heat-transfer data to evaluate the calculating procedures used in making temperature estimates for the Titan ICBM design.

The results of the first flight test of the series are presented in reference 1. Results of the second flight test are reported herein. The present model differed from the first in the shape of the reentry nose. The nose design used in this test is designated by the contractor as P-13 whereas the nose used in the first test was designated as P-200.

The flight models were designed and constructed by the Titan air-frame contractor, the Martin Company of Denver, Colorado. They were instrumented at the NACA Langley Laboratory and flight tested at the Langley Pilotless Aircraft Research Station at Wallops Island, Va.

Heat-transfer data in the form of Stanton numbers obtained from the flight measurements are presented herein. These Stanton numbers were reduced from measured wall temperatures and measured flight and wind-tunnel pressures. The Mach number range for which data were obtained was from 1.04 to 3.91 and the corresponding free-stream Reynolds number per foot ranged from 6.1×10^6 to 23.4×10^6 .

Also presented herein are drag coefficients for Mach numbers from 1.5 to 3.5.

SYMBOLS

c_p	specific heat of air at constant pressure, Btu/slug- $^{\circ}$ R
$c_{p,w}$	specific heat of Inconel, Btu/lb- $^{\circ}$ R
C_p	pressure coefficient, $\frac{p_l - p_{\infty}}{q_{\infty}}$
h	heat-transfer coefficient, Btu/sec-ft 2 - $^{\circ}$ R
H	altitude, ft
K	conductivity of air, Btu/sec-ft- $^{\circ}$ R
M	Mach number
N_{Pr}	Prandtl number, $c_p \mu / K$
N_{St}	Stanton number, $h / c_p \rho V$

P_1, P_2, \dots, P_7 pressure stations (see fig. 2)

p pressure, lb/sq in.

q dynamic pressure, $\rho V^2/2$, lb/sq in.

R Reynolds number, $R_{\infty,1} = \frac{\rho V}{\mu}$ and $R_l = \frac{\rho V x}{\mu}$

η_r recovery factor, $\frac{T_{aw} - T_l}{T_s - T_l}$

T temperature, $^{\circ}$ R

T_1, T_2, \dots, T_{12} thermocouple stations (see fig. 2)

t time, sec

v velocity, ft/sec

x distance along body from stagnation point, in.

ρ density, slugs/cu ft

τ thickness, ft

μ viscosity of air, slugs/ft-sec

Subscripts:

∞ free stream

l outside boundary layer

w pertaining to wall

aw adiabatic wall

s stagnation

l based on a length of 1 foot

MODEL

The model used in this test was a 1/18-scale Inconel model of the Titan ICBM mounted on the forward end of a Cajun rocket motor. Photographs of the model are presented in figure 1. A sketch of the model, with thermocouple locations, pressure pickups, and skin thicknesses, is presented in figure 2. The nose used in this test is designated by the contractor as P-13; a detail of this nose is presented in figure 2(b). The nose was polished to a surface roughness of 4 to 8 microinches (measured from peak to valley by an interference microscope) and had seven thermocouples and four pressure pickups. With the exception of the stagnation pressure pickup, the pressures are located diametrically opposite the corresponding temperature measuring stations.

The cylinder-flare portion of the model was polished to a surface roughness of 8 to 12 microinches. There were three thermocouples and one pressure pickup on the cylinder, and two thermocouples and two pressure pickups on the flare. The flare angle was 7.5°.

INSTRUMENTATION AND TESTS

The model was instrumented with a standard NACA 10-channel telemeter. One channel was used in transmitting measured temperature data, seven channels were used in transmitting pressure data, and two channels were used to transmit longitudinal accelerations. Temperature measurements were made at 12 stations along the body. (See fig. 2.) These measurements were commutated during flight at such a rate that every measurement was sampled at about every 0.2 second. The pressures and accelerations were measured continuously during flight.

The model was launched at an elevation angle of 67°42' with respect to the horizontal. The Cajun rocket motor accelerated the model to a Mach number of 3.91 at an altitude of 5,450 feet. Velocity data were obtained by means of CW Doppler radar, and altitude and flight path were measured with an NACA modified SCR-584 tracking radar. Atmospheric and wind conditions were measured by radiosonde balloons launched near the time of flight and tracked with a Rawin set AW/GMD-1A. Atmospheric conditions and altitude related to model flight time are shown in figure 3. Free-stream Mach number and free-stream Reynolds number per foot are shown plotted against time in figure 4.

DATA REDUCTION

From flight records of the model, the following information was obtained:

- (1) Atmospheric properties and altitude (fig. 3).
- (2) Free-stream Mach and Reynolds numbers (fig. 4).
- (3) Pressure coefficients (fig. 5).
- (4) Skin-temperature measurements (fig. 6).
- (5) Stanton numbers (fig. 7).
- (6) Drag coefficients (fig. 8).

From measured wall temperatures, flight conditions, and measured pressures, Stanton numbers ($N_{St} = h/c_p \rho V$) were obtained by using the following relation:

$$N_{St}(c_p \rho V)_l = \frac{(\tau_p)_w c_{p,w}}{T_{aw} - T_w} \frac{dT_w}{dt}$$

Heat losses due to conduction and radiation were found to be negligible when compared with heat transfer caused by convection. The skin thickness τ_w was measured and the density ρ_w of the Inconel was known.

The specific heat of Inconel $c_{p,w}$ is given in reference 2 as a function of temperature. The adiabatic-wall temperature T_{aw} was computed from the relation

$$T_{aw} = \eta_r(T_s - T_l) + T_l$$

where the recovery factor η_r was determined from the usual turbulent relation $\eta_r = N_{Pr}^{1/3}$ with Prandtl number evaluated at the wall temperature.

A discussion of the accuracy of the heat-transfer coefficients obtained from data measured in free flight is presented in appendix A of reference 3. Measured skin temperatures of the test model have a calculated error of $\pm 22^\circ$.

The local conditions for the test model were obtained by using measured pressures and normal shock relations (ref. 4).

Tabulated data pertinent to the test are given in table I for all thermocouple locations.

RESULTS AND DISCUSSION

Pressure Measurements

The measured pressures on the body are shown in figure 5 and are expressed as pressure coefficients as a function of free-stream Mach number for both the accelerating and decelerating period of flight. Also presented in figure 5, for comparison, are unpublished wind-tunnel pressure coefficients at various Mach numbers, for the same configuration as the free-flight model. These wind-tunnel pressure coefficients were obtained from tests conducted in the Langley Unitary Plan wind tunnel for the Martin Company on a 1/25-scale model of the Titan.

In figure 5(a), pressure coefficients are presented for the nose conical section having a 9° semiangle, designated C_{p2} , and for the nose conical section having an 11° semiangle, designated C_{p3} and C_{p4} . The pressure coefficients at these stations are in good agreement with the given wind-tunnel data. Also presented in figure 5(a), for stations P_3 and P_4 , designated C_{p3} and C_{p4} in the figure, are free-flight pressure coefficients on an 11° semiangle conical section described in reference 1.

In figure 5(b), pressure coefficients on the cylinder-flare portion of the model are given. These measurements are in good agreement with the given wind-tunnel data.

Heat Transfer

Figure 6 presents the variation of measured wall temperature with time for all 12 thermocouple stations. In figure 6(c) the measured data points for station T_8 are presented in order to illustrate the fairing accuracy of the temperature curves. Figure 7 presents measured heat-transfer coefficients expressed as local Stanton number N_{St} as a function of distance along the body from the stagnation point to the measurement temperature station. Because no pressure measurements were taken at

stations T_2 , T_9 , and T_{10} , the local Stanton numbers for these stations were calculated by using wind-tunnel pressure measurements. The Stanton numbers for the remaining stations were calculated by using the local measured pressure at these stations. Also presented in figure 7 are the results obtained by the Van Driest theory for laminar and turbulent flow (ref. 5) over both flat and conical regions. Theoretical Stanton number was assumed equal to 0.6 of the skin friction coefficient.

Figures 7(a) to 7(c) present Stanton numbers for the earlier portion of the flight and indicate that the flow over all stations is turbulent. The data presented are approximately 20 percent lower than the results obtained by the Van Driest turbulent theory for both the flat-plate and conical regions where the theory is based on length from the stagnation point and local condition. This same difference on the cylinder flare was also observed in reference 1 for approximately the same flight conditions.

In figures 7(d) to 7(j), all stations appear to be turbulent except for station T_1 ($x = -4.06$), which is located on the 9° semiangle nose conical section. At Mach number 3.55, during the decelerating portion of flight, station T_1 abruptly turns laminar and remains laminar until the model has decelerated to Mach number 2.26. A short burst of turbulent flow is present until Mach number 1.67. The flow then returns laminar and remains laminar for the remaining time for which data are presented. These sudden changes in flow at station T_1 can also be seen in the temperature time curve of figure 6(a) where the curve for station T_1 suddenly flattens. This curve also shows that the flow after 13.3 seconds might be turbulent.

The data in figures 7(d) to 7(j), for the cylinder flare, agree better with the Van Driest turbulent theory at the latter part of flight. This was also observed in reference 1. The data for the laminar periods of flow agree well with the Van Driest laminar theory of reference 5.

Drag Measurement

Drag coefficients for the complete configuration were measured during the decelerating portion of the flight and are presented in figure 8 as a function of free-stream Mach number. In order to evaluate the drag coefficient of the test model, drag for the Cajun, fins, base, and antenna had to be obtained either experimentally or by calculation. Drag of the Cajun and fins was obtained from reference 6, and the base drag was obtained from reference 7. The fins used in this test were identical to the fins used in reference 6. The drag coefficient for the Titan model shown in the lower part of figure 8 is based on the diameter at the base of the model, 0.2485 square foot, and excludes base drag.

CONCLUDING REMARKS

A flight test has been made of a second 1/18-scale model of the Titan missile up to a Mach number of 3.91 and Reynolds number per foot of 23.4×10^6 . With the exception of the foremost measuring station, turbulent heating rates were measured over the model during the flight. The heat-transfer data over the body were approximately 20 percent lower than the results obtained by the Van Driest theory during the accelerating portion of flight, but were in much closer agreement during the decelerating portion of the flight. Drag coefficients were also obtained for a Mach number range of 1.5 to 3.5.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 20, 1958.

REFERENCES

1. Graham, John B., Jr., Chauvin, Leo T., and Speegle, Katherine C.: Heat-Transfer and Pressure Measurements From a Flight Test of a 1/18-Scale Model of the Titan Intercontinental Ballistic Missile Up to a Mach Number of 3.95 and Reynolds Number Per Foot of 23×10^6 . NACA RM SL57L16a, 1957.
2. Ginnings, Defoe C., and Thomas, Eugenia: The Electrical Resistance and Total Radiant Emittance of Inconel in the Range 0° to 1000° C. NBS Rep. 4111 (NACA Contract S54-52), Nat. Bur. Standards, May 1955.
3. Piland, Robert O., Collie, Katherine A., and Stoney, William E.: Turbulent and Laminar Heat-Transfer Measurements on a 1/6-Scale NACA RM-10 Missile in Free Flight to a Mach Number of 4.2 and to a Wall Temperature of 1400° R. NACA RM L56C05, 1956.
4. Ames Research Staff: Equation, Tables, and Charts for Compressible Flow. NACA Rep. 1135, 1953. (Supersedes NACA TN 1428.)
5. Van Driest, E. R.: The Problem of Aerodynamic Heating. Aero. Eng. Rev., vol. 15, no. 10, Oct. 1956, pp. 26-41.
6. Lee, Dorothy B.: Flight Performance of a 2.8 KS 8100 Cajun Solid-Propellant Rocket Motor. NACA RM L56K01, 1957.
7. Love, Eugene S.: Base Pressure at Supersonic Speeds on Two-Dimensional Airfoils and on Bodies of Revolution With and Without Fins Having Turbulent Boundary Layers. NACA TN 3819, 1957. (Supersedes NACA RM L53C02.)

TABLE I. - TEST DATA

(a) Thermocouple 1

TABLE I.- TEST DATA - Continued

(b) Thermocouple 2

TABLE I.- TEST DATA - Continued

(c) Thermocouple 3

TABLE I.-- TEST DATA - Continued

(d) Thermocouple 4

TABLE I.- TEST DATA - Continued

(e) Thermocouple 5

TABLE I.- TEST DATA - Continued

(f) Thermocouple 6

TABLE I.- TEST DATA - Continued

(g) Thermocouple 7

TABLE I.- TEST DATA - Continued

(h) Thermocouple 8

TABLE I.- TEST DATA - Continued

(1) Thermocouple 9

TABLE I.- TEST DATA - Continued

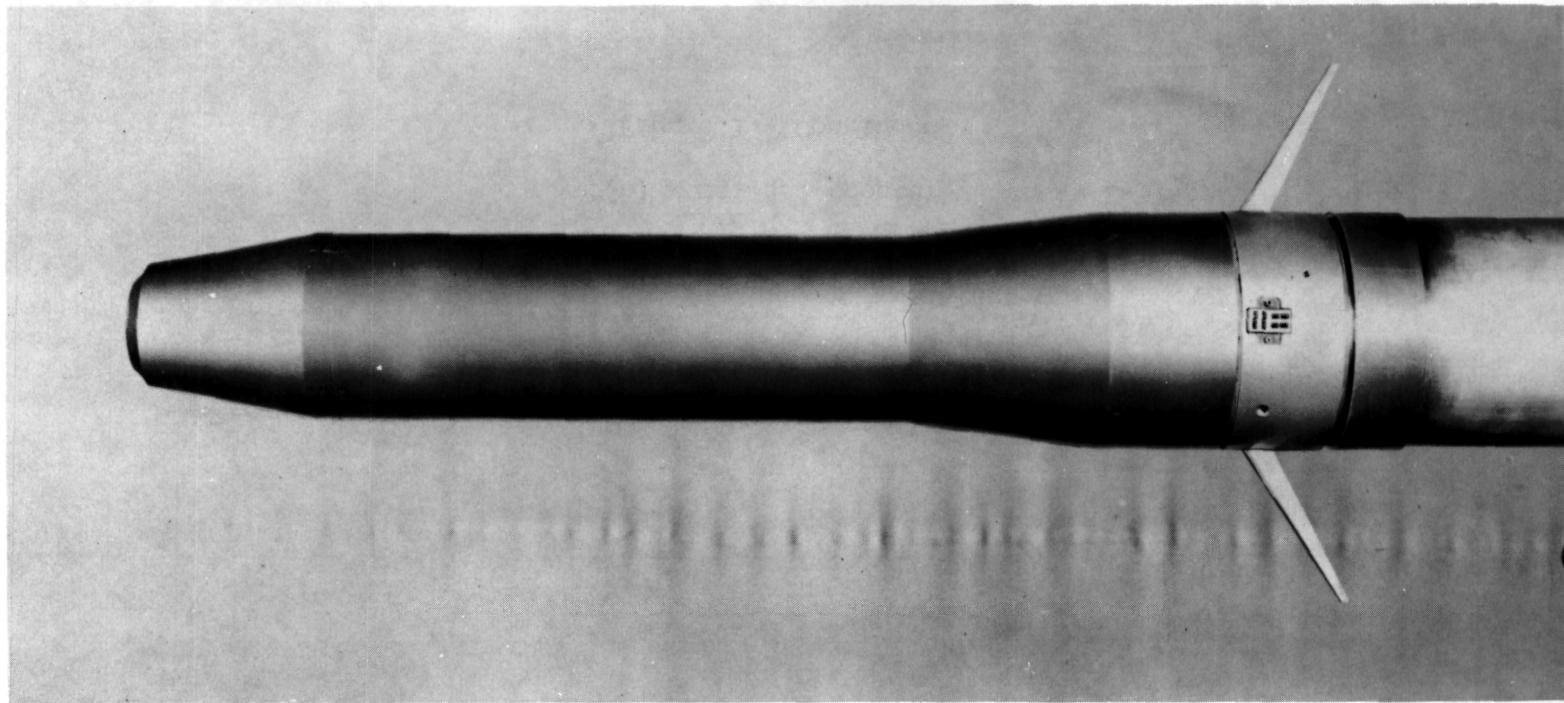
(j) Thermocouple 10

TABLE I. - TEST DATA - Continued

(k) Thermocouple 11

TABLE I.- TEST DATA - Concluded

(i) Thermocouple 12

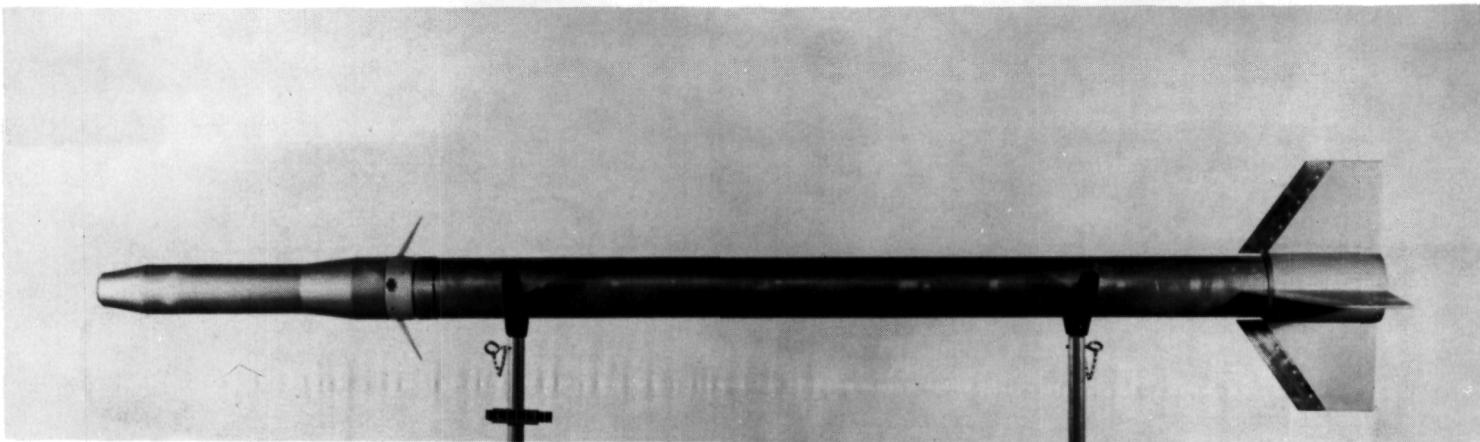


(a) Test portion of model.

L-57-3916

Figure 1.- Photograph of model.

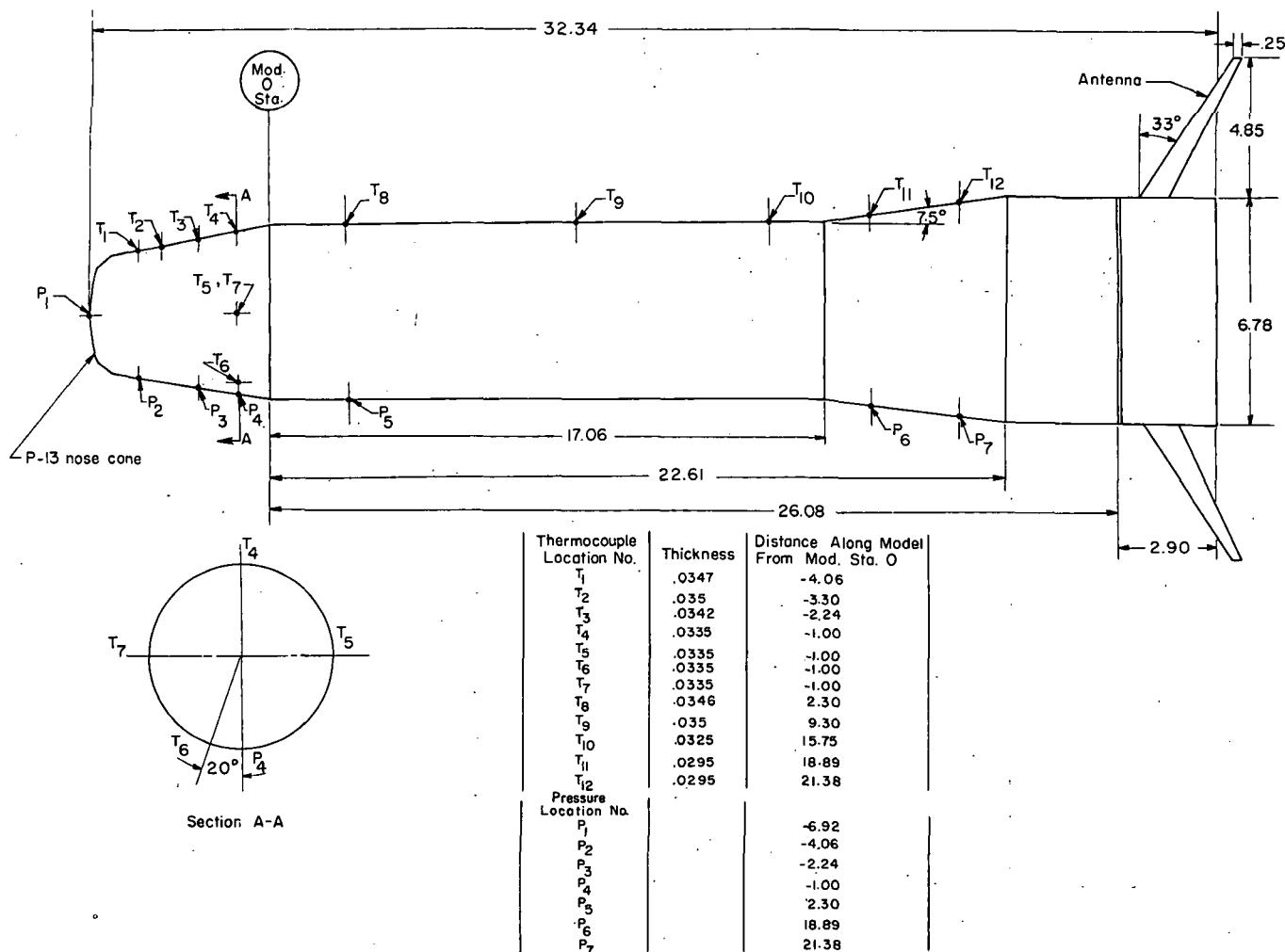
NACA RM SL58B10



(b) Model and booster.

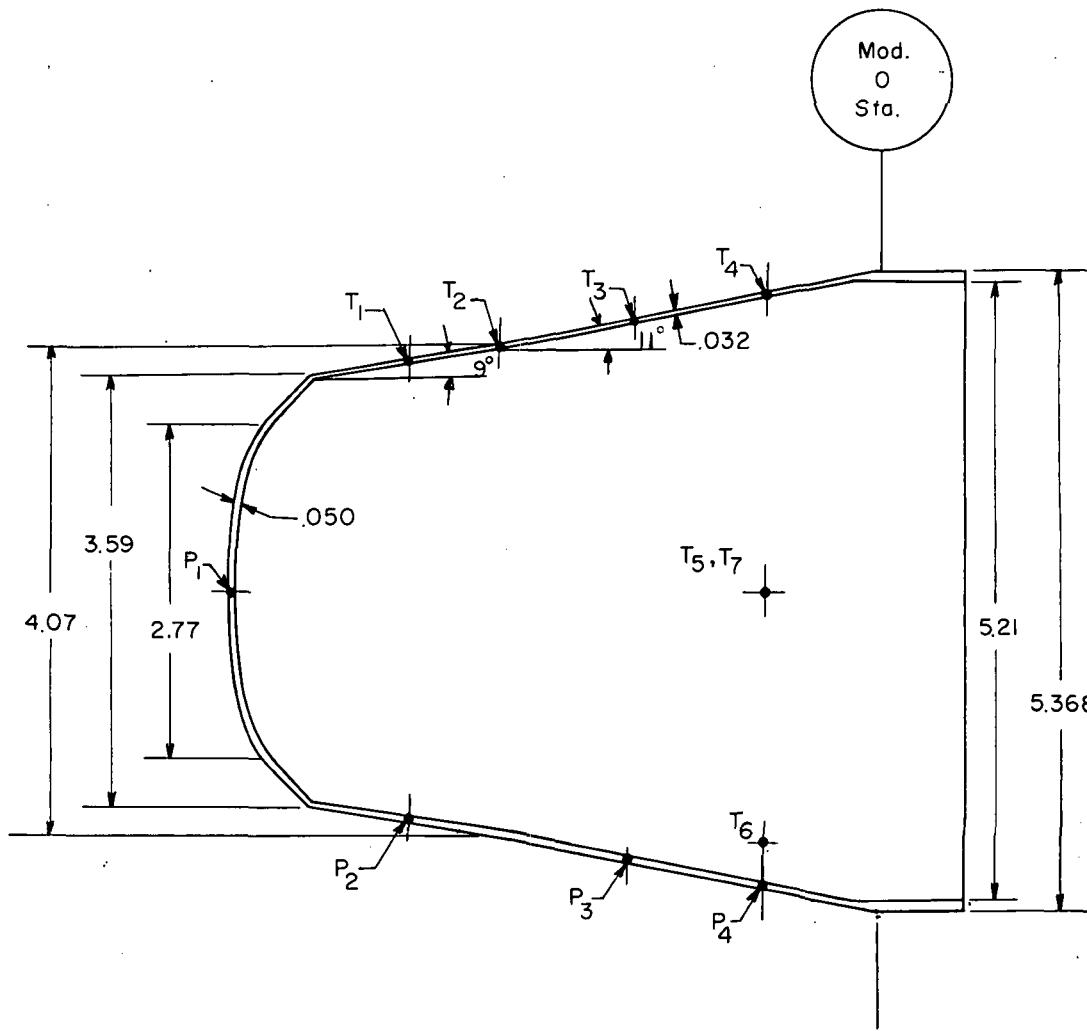
L-57-3915

Figure 1.- Concluded.



(a) Complete configuration.

Figure 2.- Sketch of model showing pressure pickups and thermocouple locations.



(b) Nose detail.

Figure 2.- Concluded.

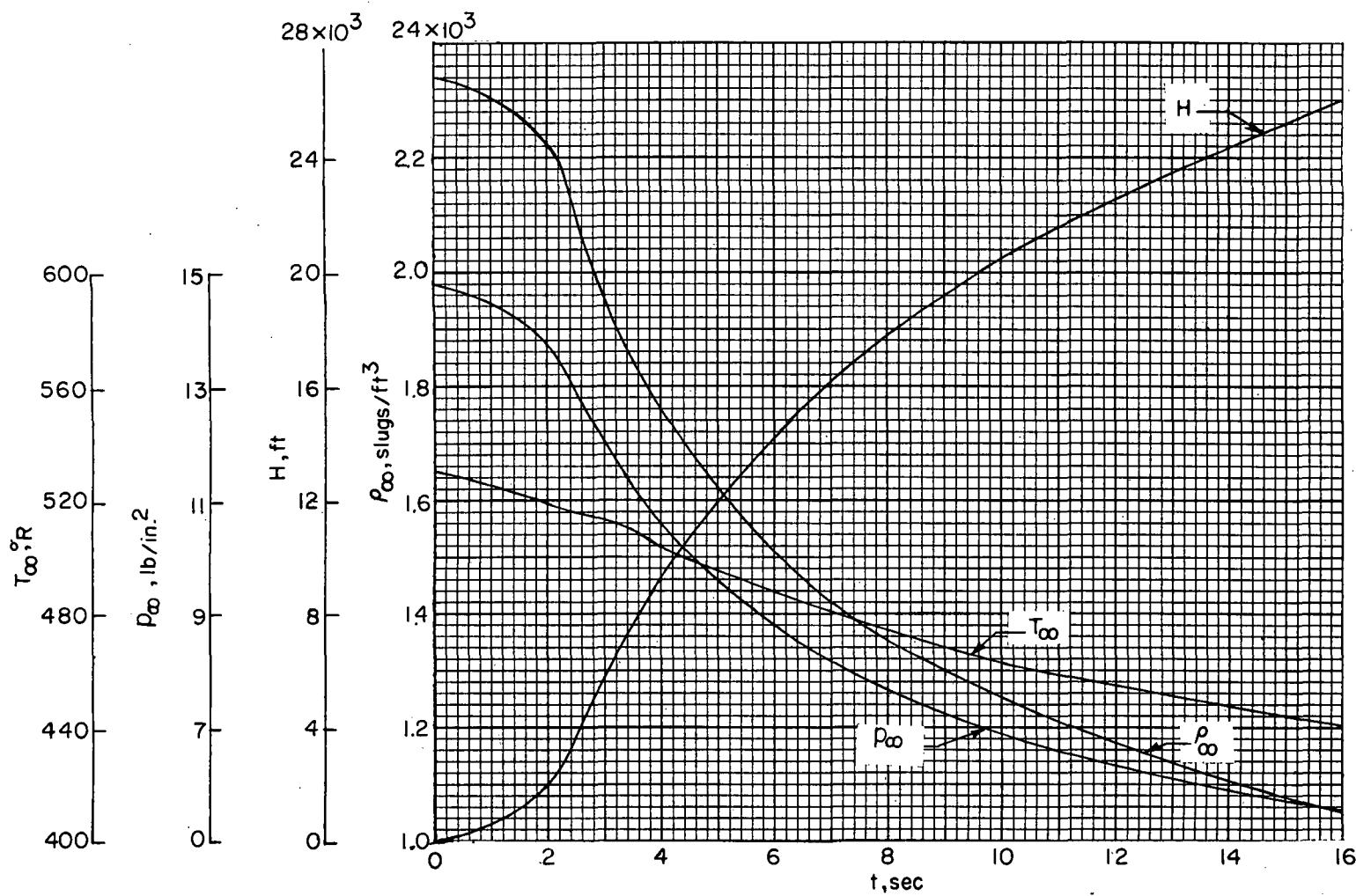


Figure 3.- Time histories of atmospheric conditions and altitude.

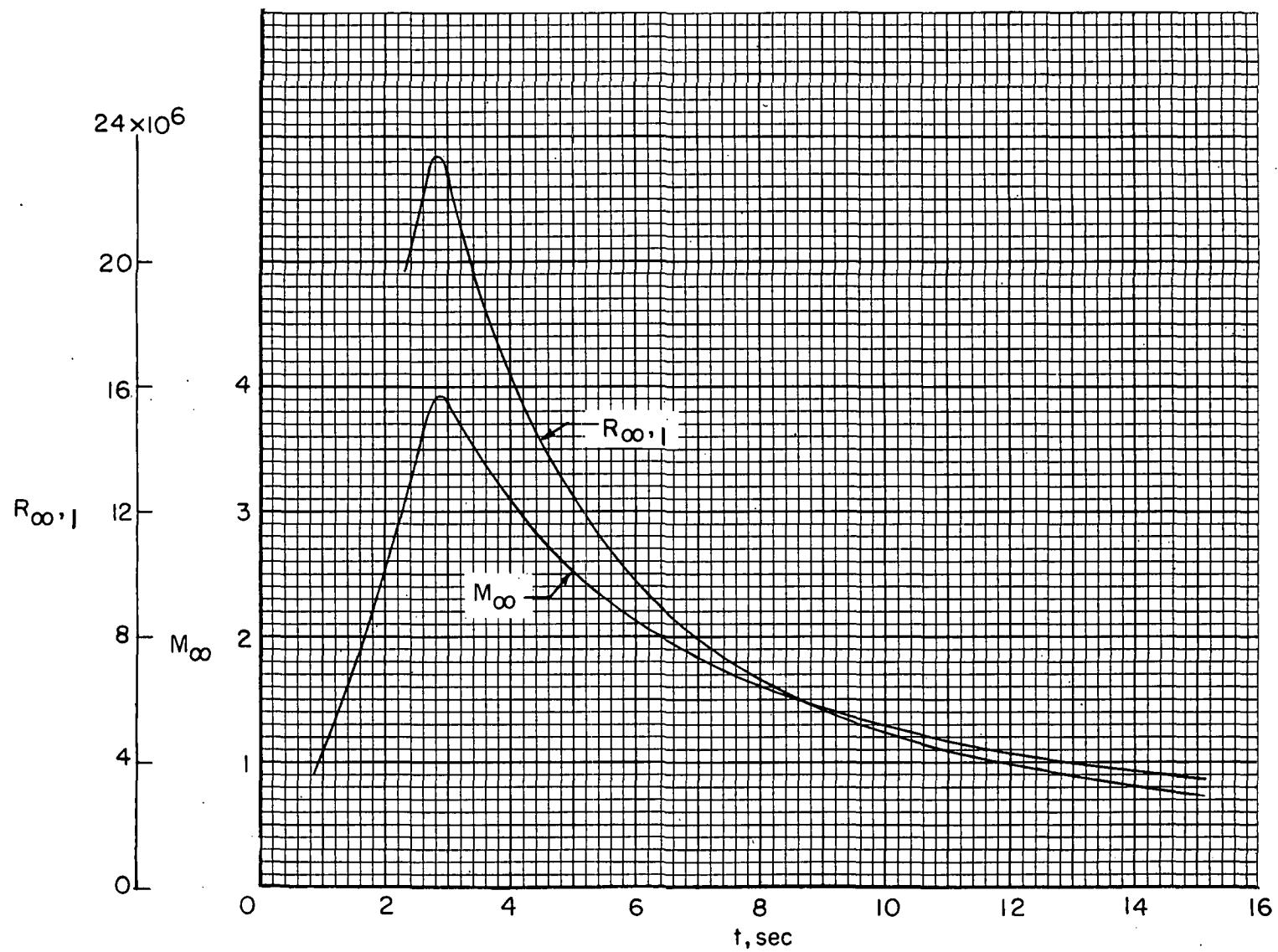


Figure 4.- Time histories of free-stream Mach number and free-stream Reynolds number per foot.

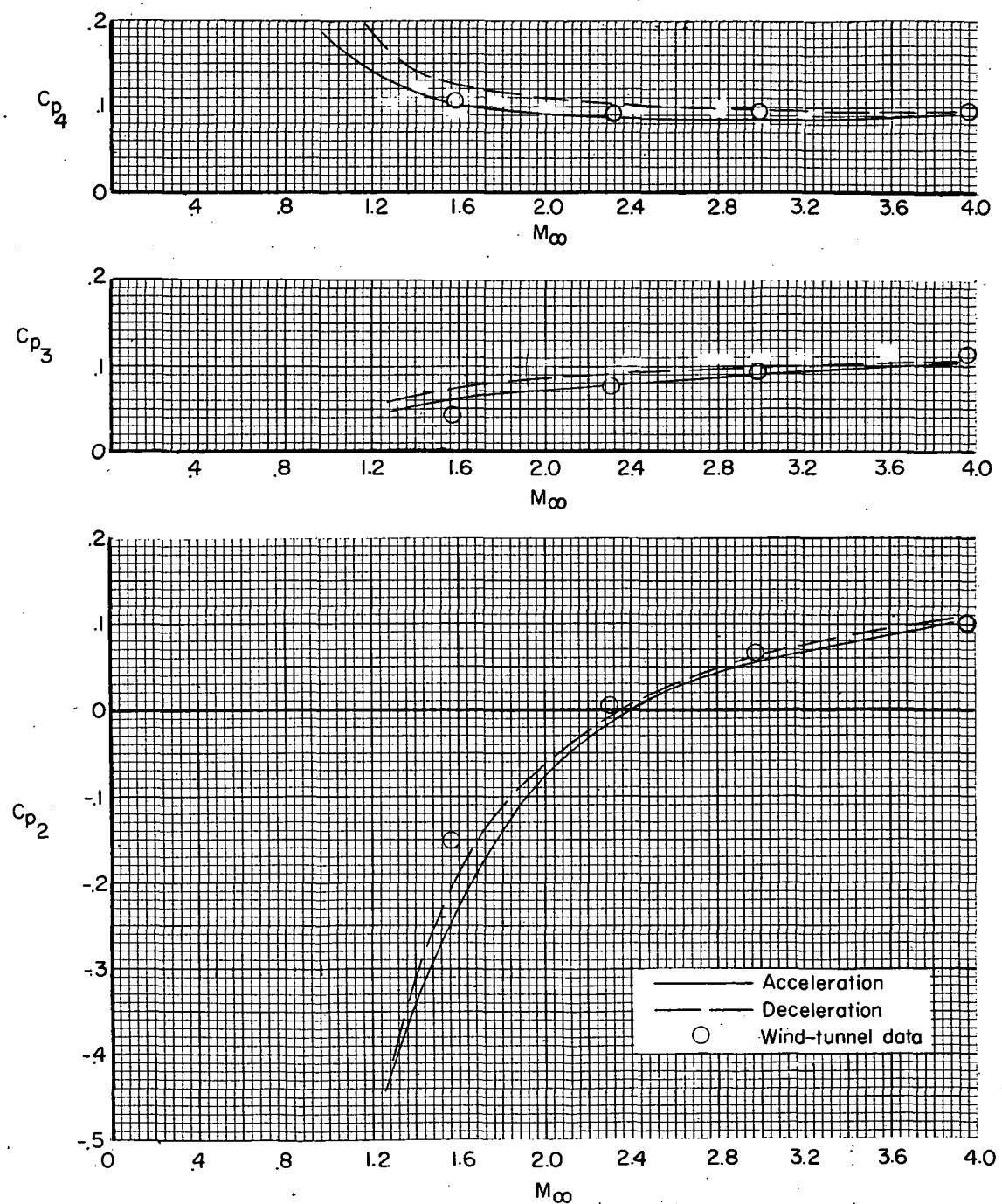
(a) Pressure stations P_2 to P_4 .

Figure 5.- Measured pressure coefficient.

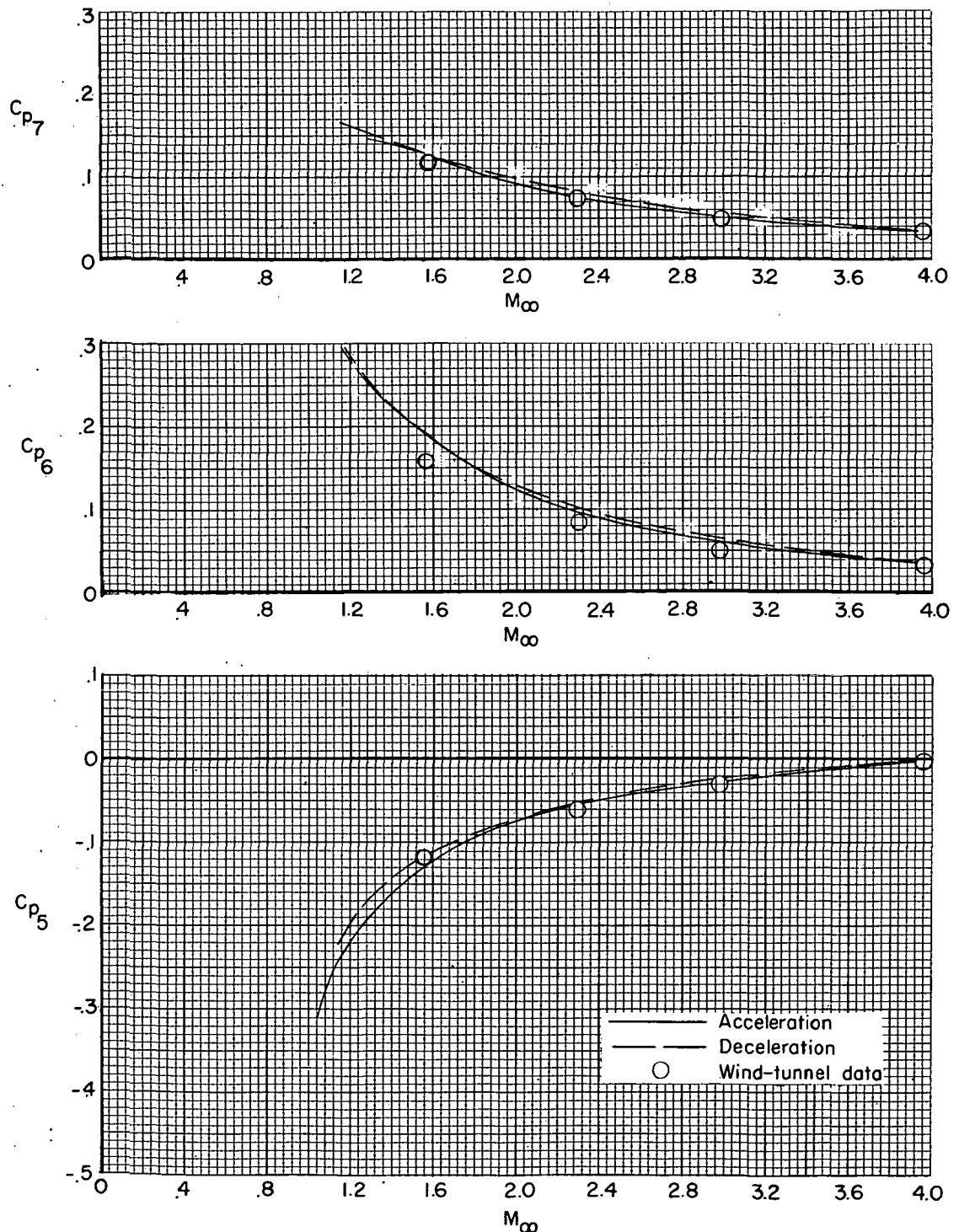
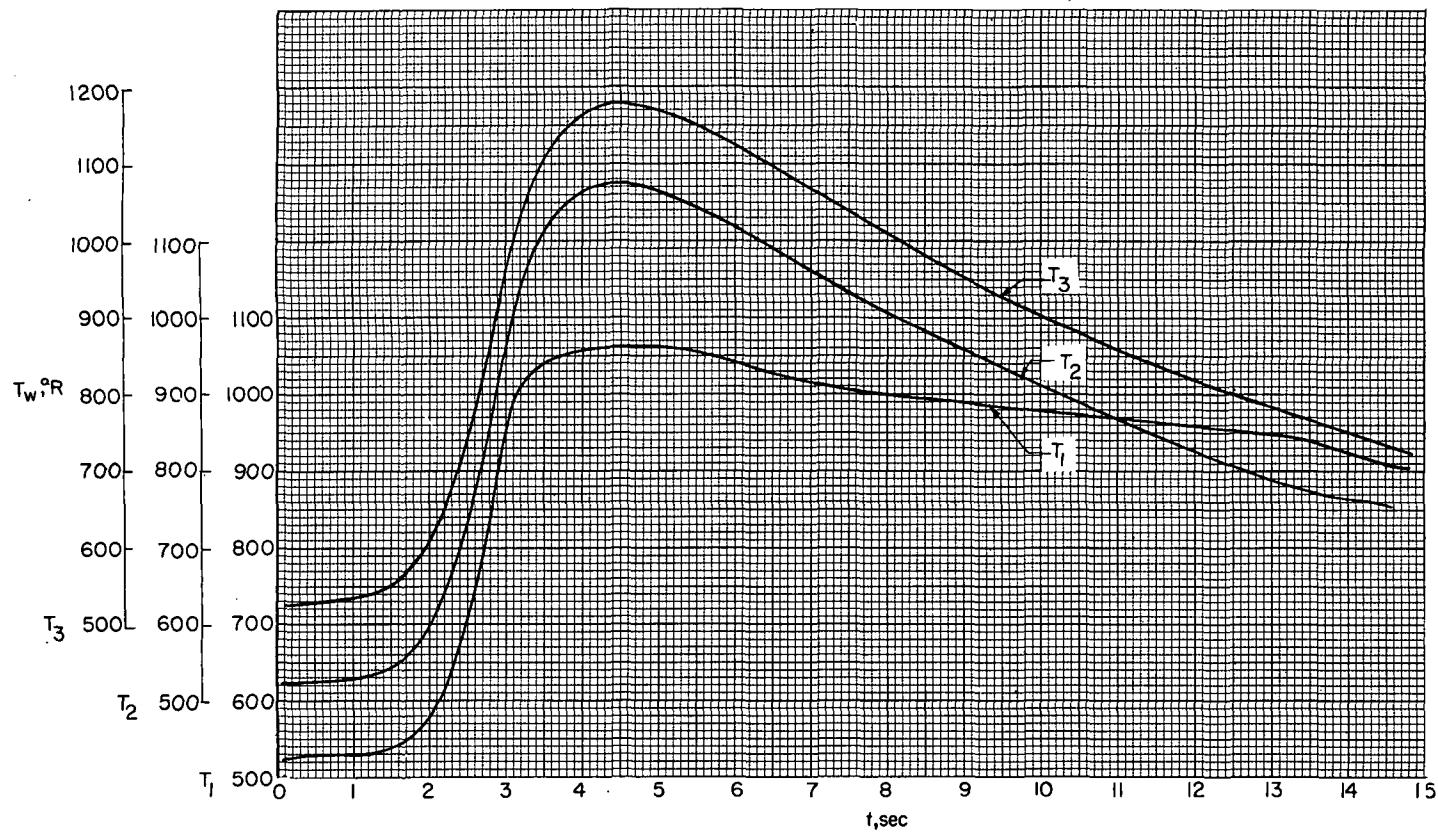
(b) Pressure stations P_5 to P_7 .

Figure 5.- Concluded.



(a) Thermocouple stations T_1 to T_3 .

Figure 6.- Skin-temperature time histories.

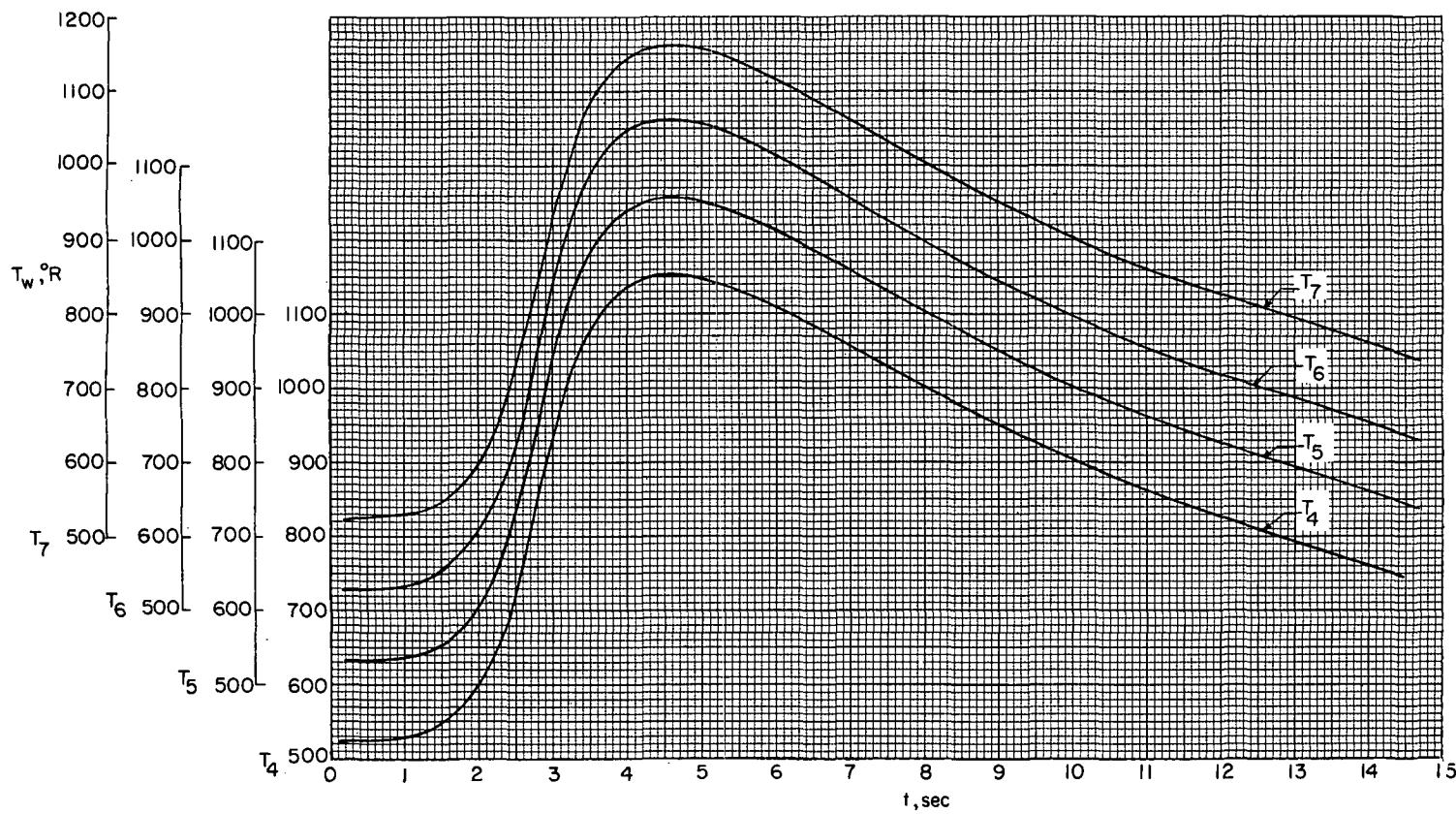
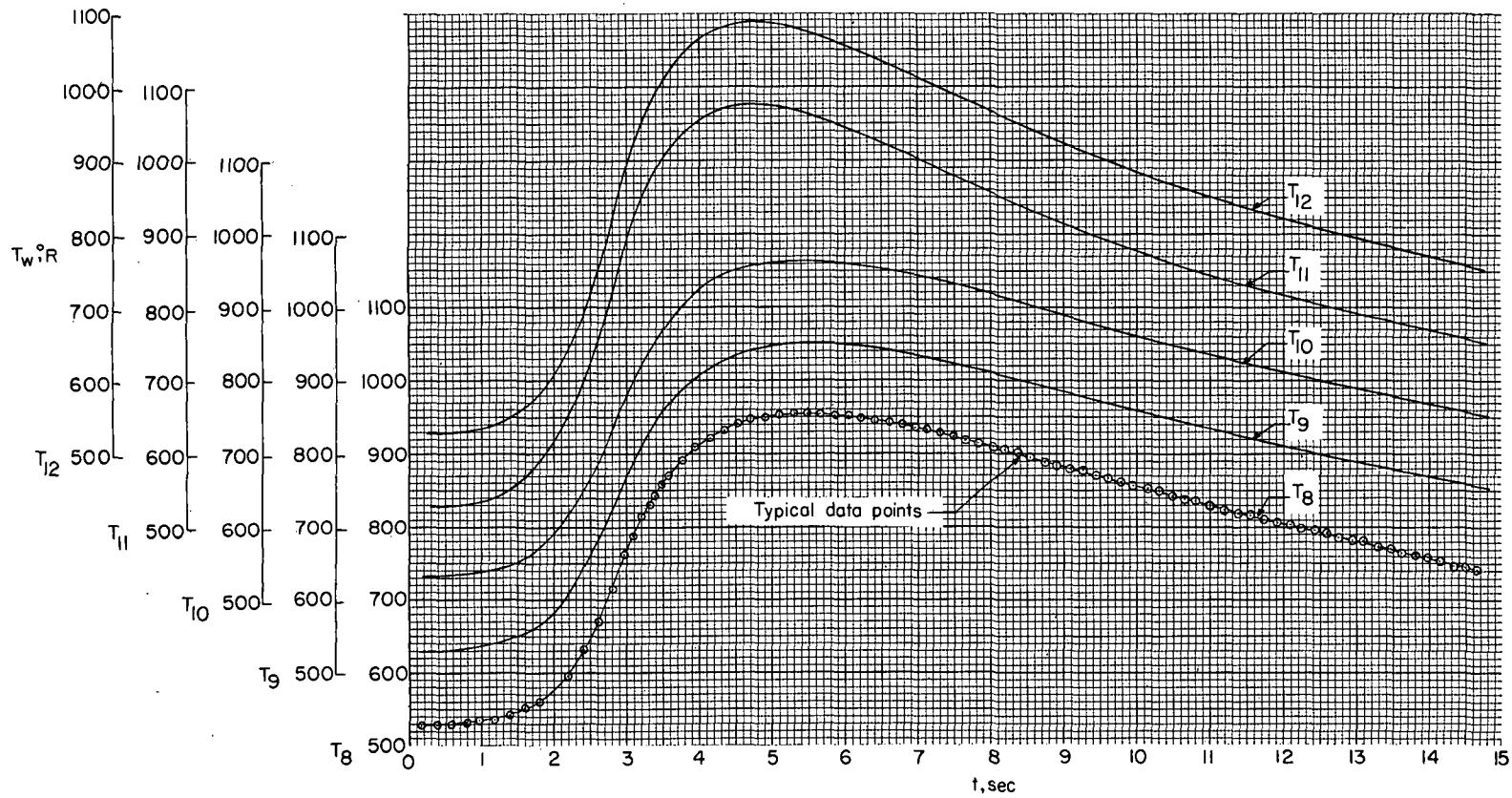
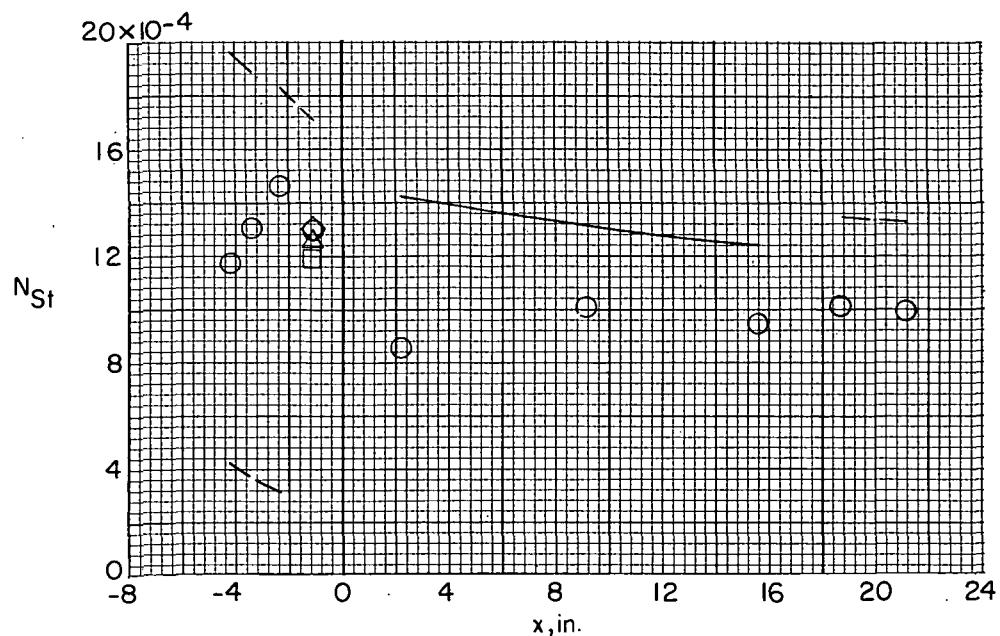
(b) Thermocouple stations T_4 to T_7 .

Figure 6.- Continued.

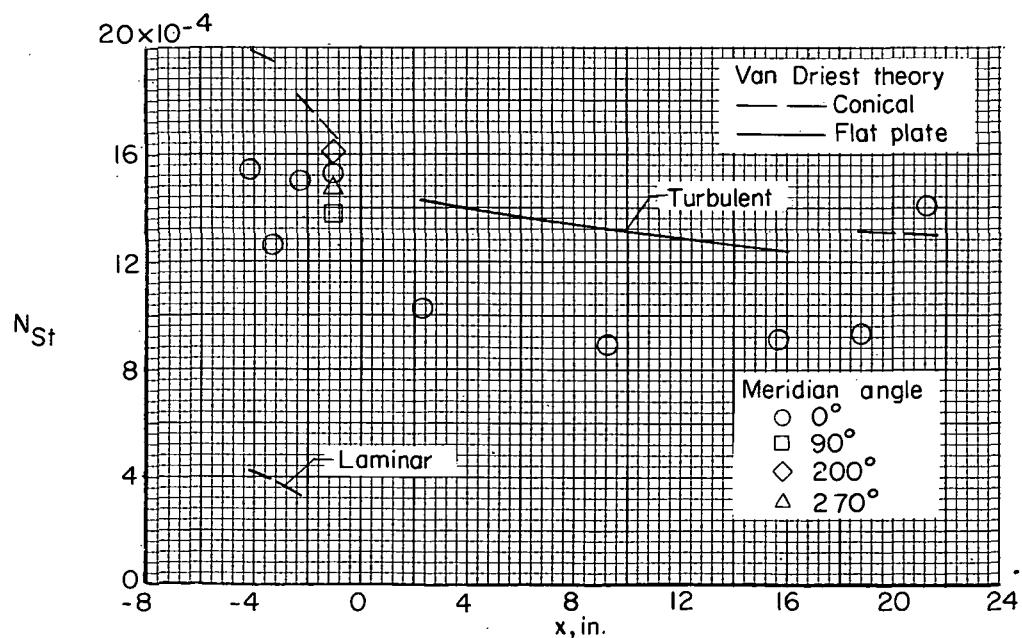


(c) Thermocouple stations T_8 to T_{12} .

Figure 6.- Concluded.

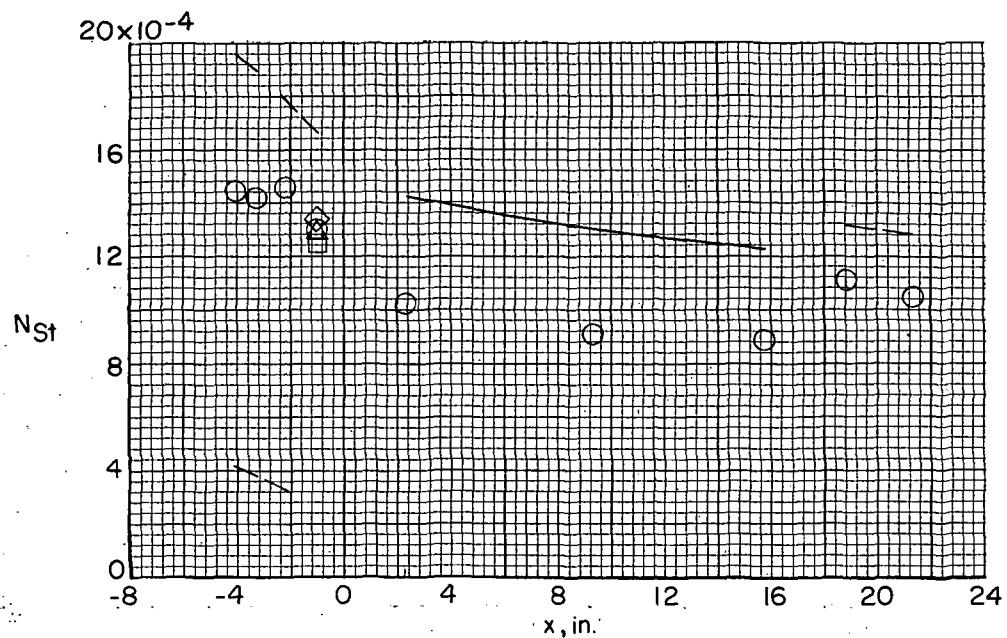


(a) $T = 2.0$ seconds; $M_\infty = 2.48$; $R_\infty,1 = 16.7 \times 10^6$.

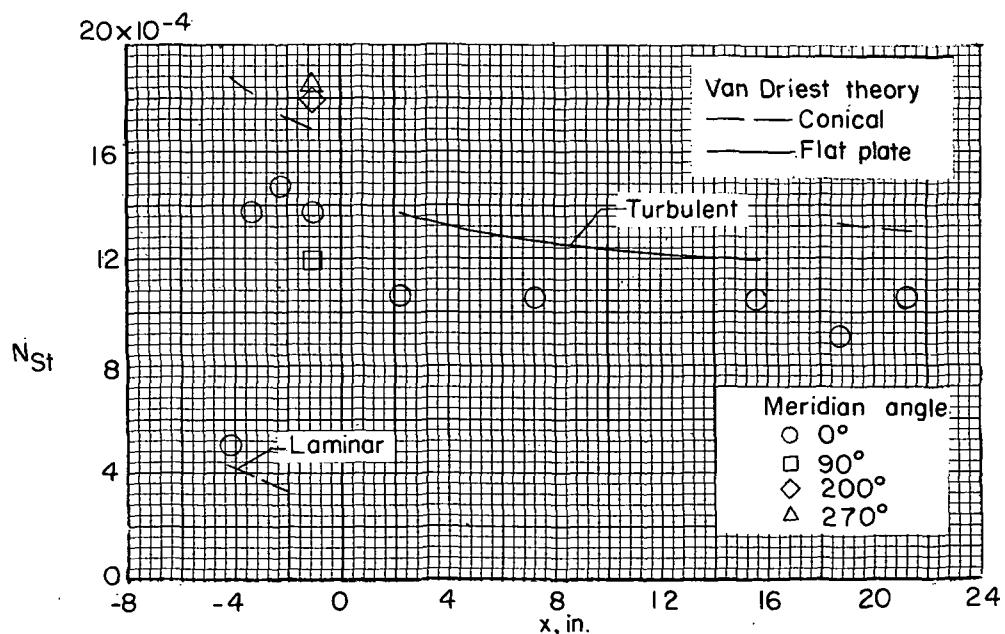


(b) $T = 2.5$ seconds; $M_\infty = 3.40$; $R_\infty,1 = 21.33 \times 10^6$.

Figure 7.- Variation of local Stanton number along the body for several Mach numbers.

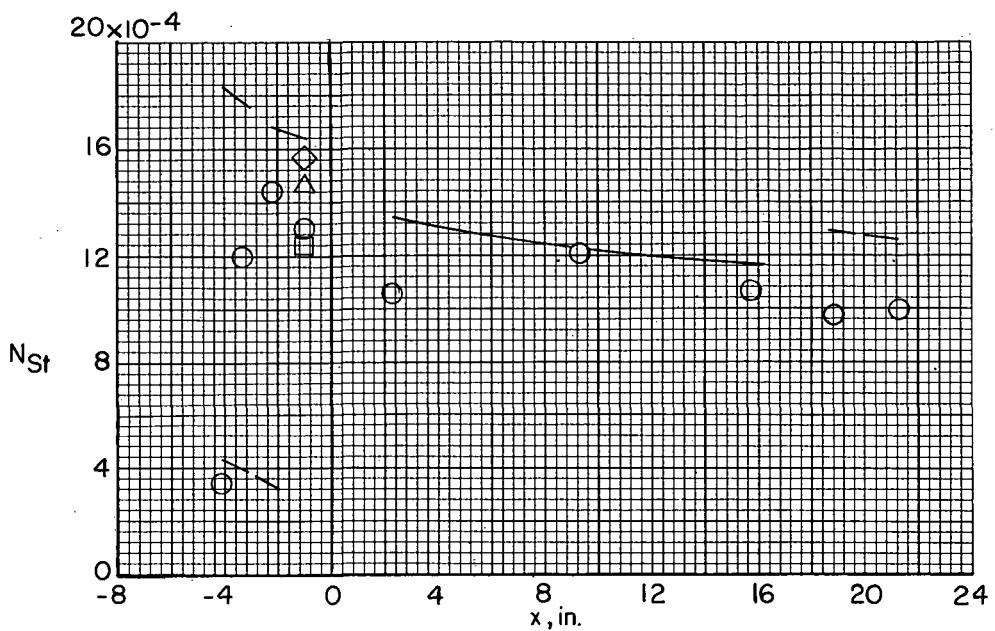


(c) $T = 2.9$ seconds; $M_\infty = 3.91$; $R_{\infty,1} = 23.30 \times 10^6$.

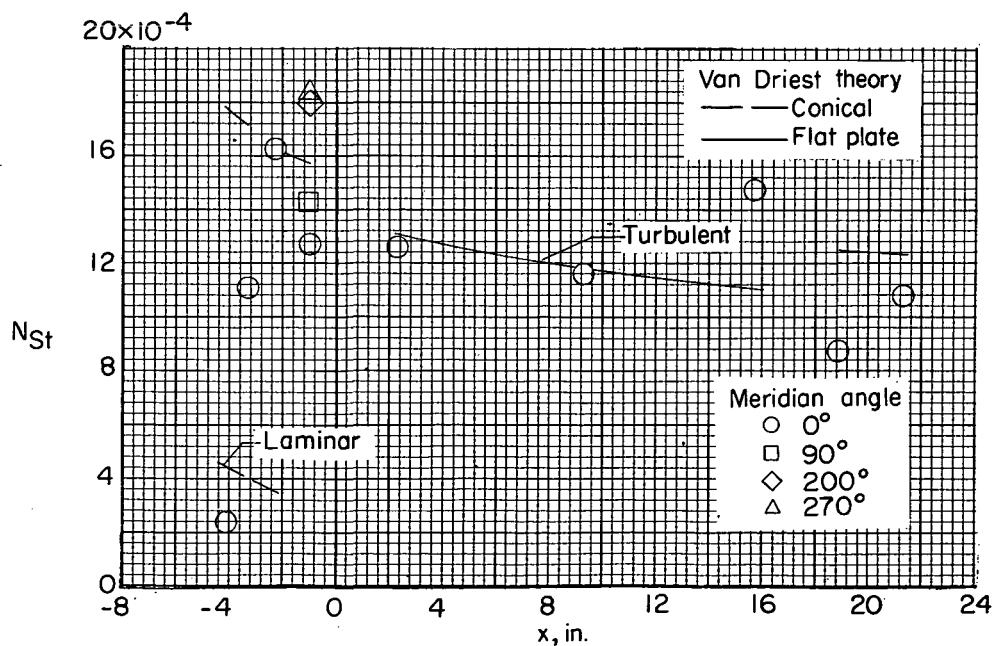


(d) $T = 3.4$ seconds; $M_\infty = 3.55$; $R_{\infty,1} = 19.88 \times 10^6$.

Figure 7.- Continued.

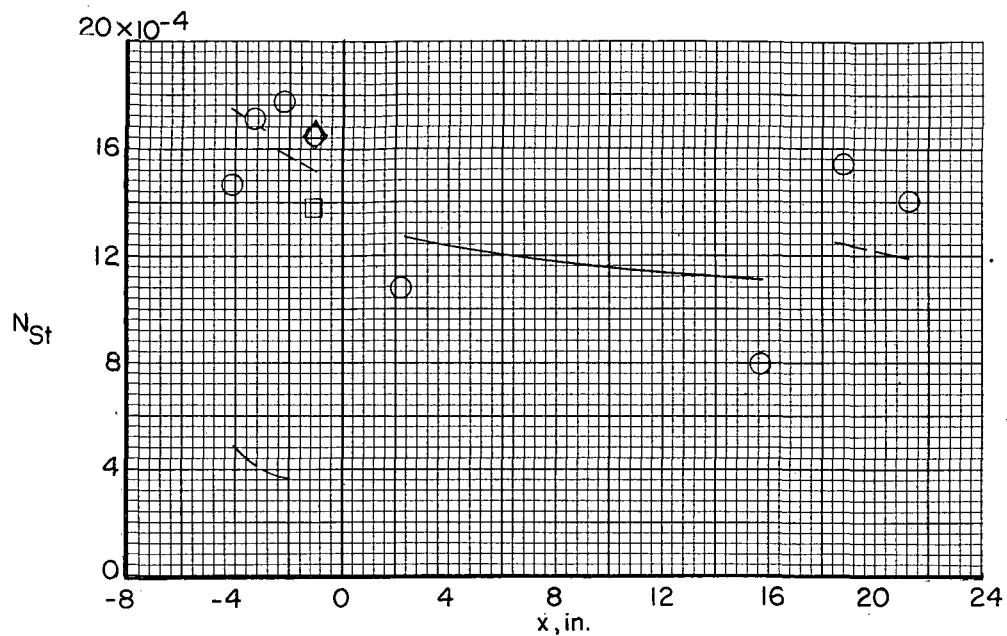


(e) $T = 3.8$ seconds; $M_\infty = 3.23$; $R_{\infty,1} = 17.47 \times 10^6$.

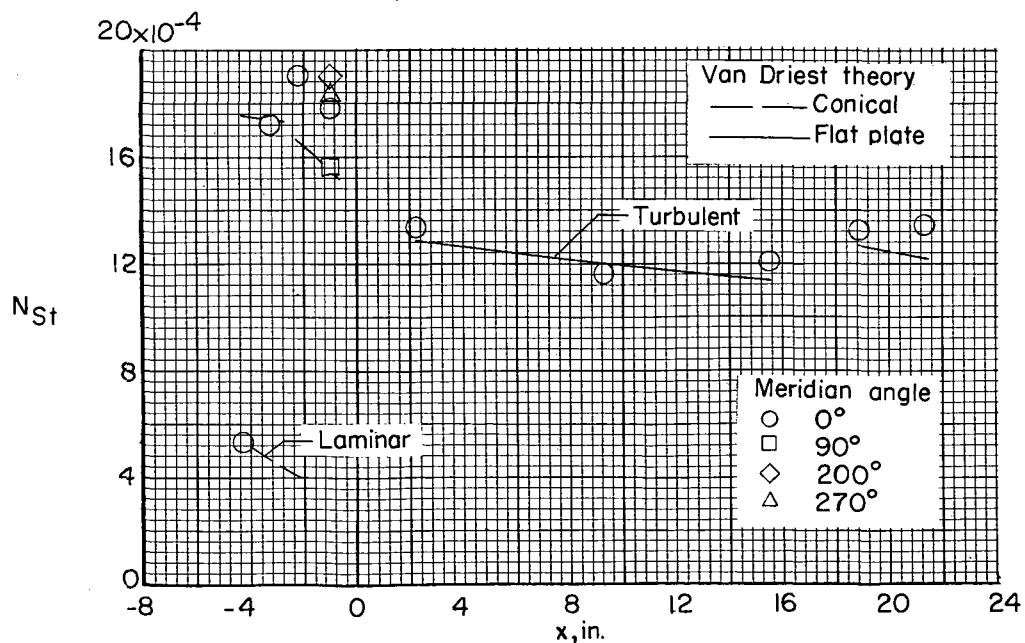


(f) $T = 4.4$ seconds; $M_\infty = 2.83$; $R_{\infty,1} = 14.59 \times 10^6$.

Figure 7.- Continued.

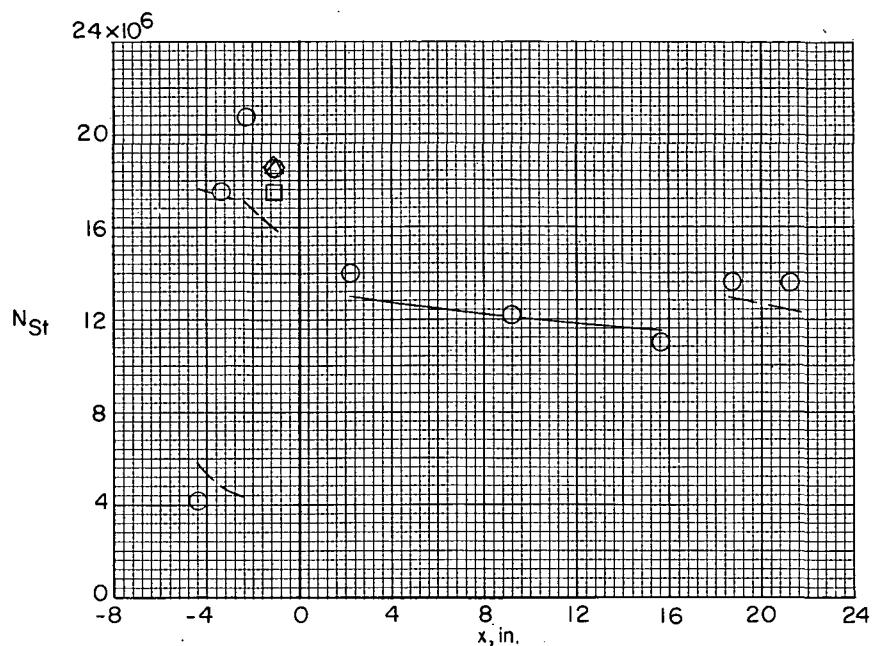


(g) $T = 5.6$ seconds; $M_{\infty} = 2.26$; $R_{\infty,1} = 10.69 \times 10^6$.

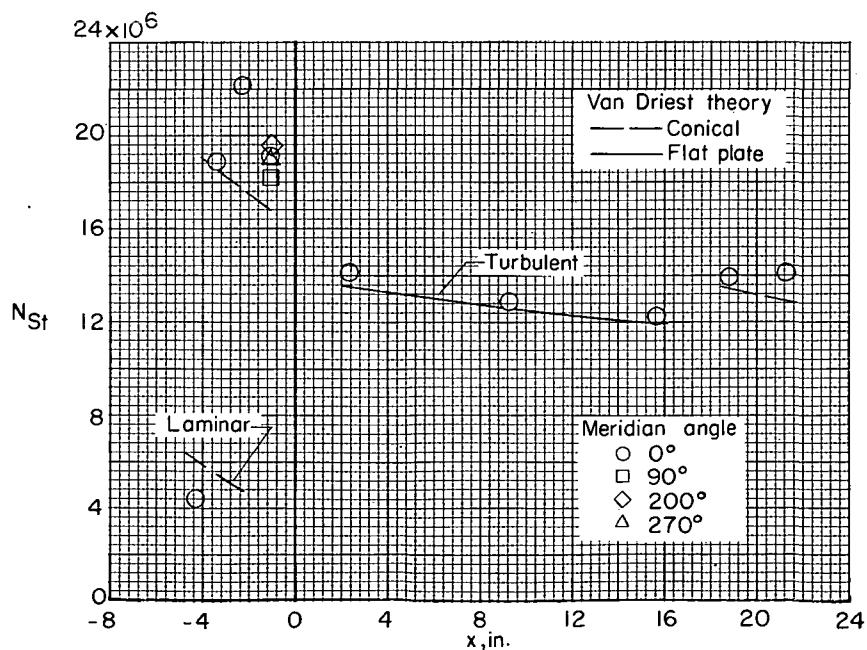


(h) $T = 7.6$ seconds; $M_{\infty} = 1.67$; $R_{\infty,1} = 7.11 \times 10^6$.

Figure 7.- Continued.



(i) $T = 8.5$ seconds; $M_\infty = 1.49$; $R_\infty,1 = 6.12 \times 10^6$.



(j) $T = 9.5$ seconds; $M_\infty = 1.33$; $R_\infty,1 = 5.27 \times 10^6$.

Figure 7.- Concluded.

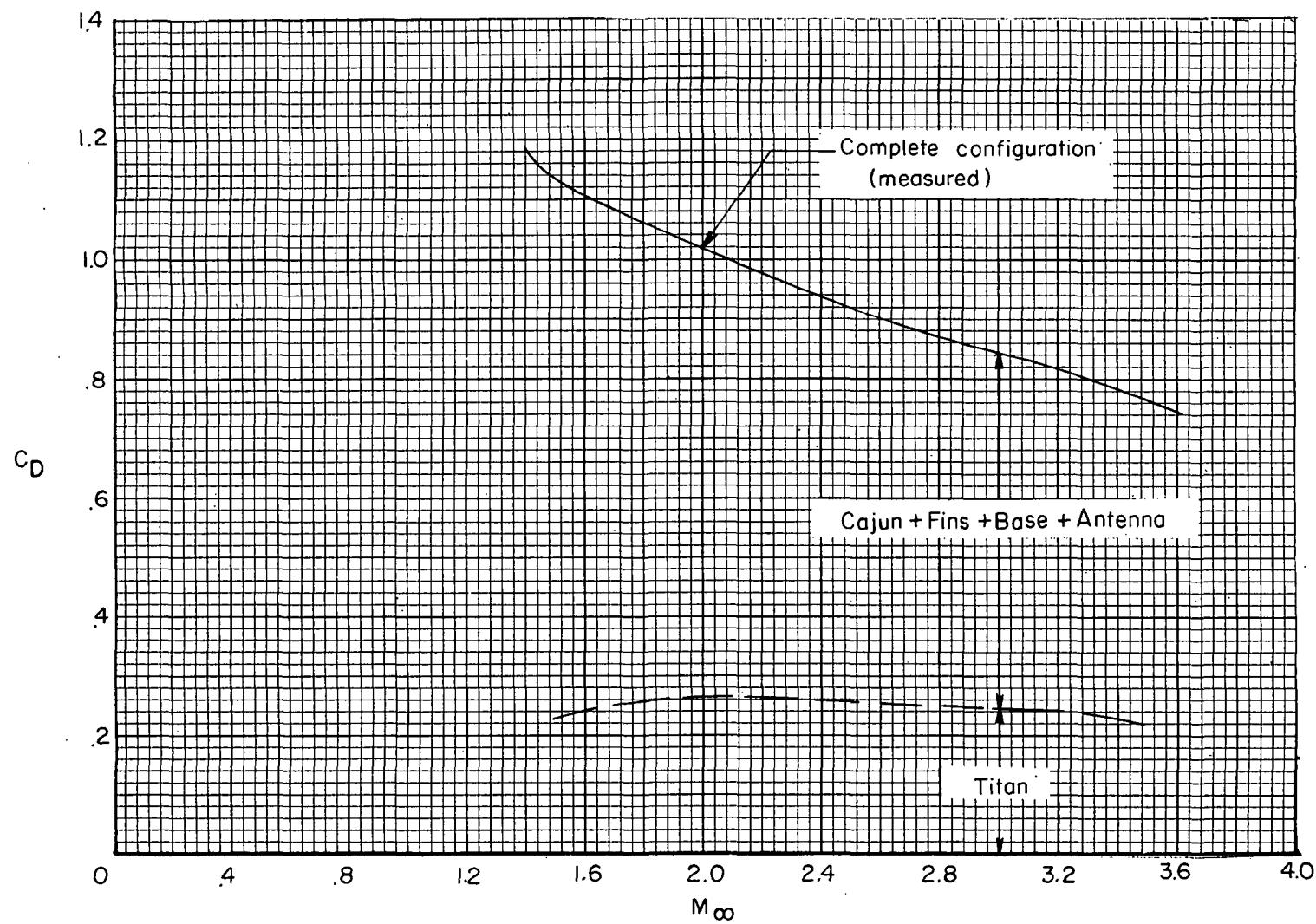


Figure 8.- Drag coefficients for complete configuration and Titan based on an area of 0.2485 square foot.

HEAT-TRANSFER AND PRESSURE MEASUREMENTS FROM A FLIGHT
TEST OF THE SECOND 1/18-SCALE MODEL OF THE TITAN
INTERCONTINENTAL BALLISTIC MISSILE UP TO A
MACH NUMBER OF 3.91 AND REYNOLDS NUMBER
PER FOOT OF 23.4×10^6

COORD. NO. AF-AM-70

By John B. Graham, Jr.

ABSTRACT

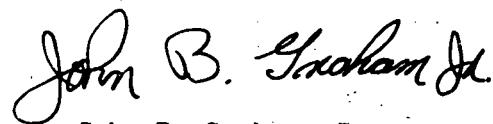
Turbulent flow was observed over the model throughout flight, with the exception of one station on the nose. Heat-transfer coefficients presented for the accelerating portion of flight were approximately on the order of 20 percent lower than results obtained by available theories; however, during the decelerating portion of the flight, the data were in good agreement with theory. Drag coefficients of the configuration were obtained for a Mach number range of 1.5 to 3.5.

INDEX HEADINGS

Flow, Laminar	1.1.3.1
Flow, Turbulent	1.1.3.2
Heating, Aerodynamic	1.1.4.1
Heat Transfer, Aerodynamic	1.1.4.2
Missiles, Specific Types	1.7.2.2

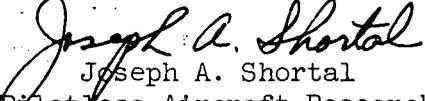
HEAT-TRANSFER AND PRESSURE MEASUREMENTS FROM A FLIGHT
TEST OF THE SECOND 1/18-SCALE MODEL OF THE TITAN
INTERCONTINENTAL BALLISTIC MISSILE UP TO A
MACH NUMBER OF 3.91 AND REYNOLDS NUMBER
PER FOOT OF 23.4×10^6

COORD. NO. AF-AM-70



John B. Graham, Jr.

Approved:



Joseph A. Shortal
Chief of Pilotless Aircraft Research Division
Langley Aeronautical Laboratory

DY

(1/20/58)